

Modeling the Impact of Seascape Evolution on the Seismic Response of Shelf and Slope Strata

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LONG-TERM GOALS

My long-term goals are to improve our understanding of the seabed on the continental shelf and slope and its evolution over geologic time, as well as to enhance our ability to extract geologic information about the seabed from geophysical data.

OBJECTIVES

The specific objectives of this project are to:

- (1) Model the potential changes to the seismic response of the seabed offshore of river mouths caused by flood sedimentation and storm reworking (addresses EuroSTRATAFORM Task D2).
- (2) Constrain the time and space scales over which different shelf and slope processes produce a stratigraphic record that is detectable in seismic reflection data (addresses EuroSTRATAFORM Task D5).
- (3) Model what is and is not preserved of the stratigraphic record across continental shelves and slopes over geologic time (addresses overarching goal of EuroSTRATAFORM).

Progress has been made on all three objectives, with objectives two and three being addressed in results by Pratson et al. (2003) and Hutton et al. (2003a,b). However, the greatest effort and most significant advances during the project have been toward achieving objective one. These efforts and achievements not only include the originally proposed numerical modeling but now also two new directions of research:

- (1) experimental modeling of the cause for seismic reflections, and
- (2) statistical analysis of ambient ocean noise data in the context of seafloor reflection loss. This summary focuses on these latter accomplishments made during FY05

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APPROACH

1) Numerical modeling of the impact of flood deposition and storm reworking on the acoustic response of the seafloor was carried out using the stratigraphic modeling system SEDFLUX2D (Syvitski and Hutton, 2001). Inputs to the model were: 100-year long sediment discharge records based on the drainage-basin characteristics of the Po and Pescara Rivers and simulated using HYDROTREND (Moorehead and Syvitski, 2003); an equally long stochastic model of wave climate based on wave measurements in the western Adriatic (Cavaleri et al., 1997); and topographic profiles of the coastal plain and shelf along the strike of the rivers from +20 m to -40 m. The outputs from SEDFLUX2D included mean grain size and bulk density. The former (mean grainsize) was used as input to Buckingham's (1997, 1998, 2000) analytical model for compressional sound speeds, which in turn were combined with the SEDFLUX2D bulk densities to simulate annual changes in seafloor reflectivity.

2) In creating discrete deposits, most depositional processes also impart an upward fining in grain size. To test whether this sorting contributes to the generation of seismic reflectors, a simple set of experiments was carried out. Four samples of quartz sand were sorted to different degrees, with one end member essentially containing only 100 μm sand and the other having a broader distribution about 100 μm that ranged from ~60-140 μm . Each sample was used to generate two deposits in a ~2 m high settling tube. The second deposit was created after the first deposit had completely settled. A 250 kHz transducer was then used to record the strength of any seismic reflection from the interface between the two deposits. Afterward, each pair of deposits was impregnated with epoxy, thin sectioned vertically across the interface between the deposits, and the thin sections then analyzed for grain-size variations across the interface using the autocorrelation algorithm developed by Rubin (2004).

3) Ambient measurements of sound in the ocean using a vertical array of hydrophones have been used to invert for reflection loss at the seabed as a function of grazing angle (Harrison and Simons, 2002). While on sabbatical at the NATO Undersea Research Centre in La Spezia, Italy, I was given the opportunity to work with these inverted data to examine how reflection loss varied with distance across a ~20km stretch of the Malta Plateau (southeast Sicilian shelf). Using inversions from successive measurements, I constructed a probability distribution function of reflection loss as a function of grazing angle for this region.

WORK COMPLETED

1) The numerical modeling of the impact of floods and storms on seabed reflectivity has been completed and written up in a manuscript (Pratson et al., in review) currently in revision for Continental Shelf Research. In addition to examining reflectivity changes on an annual basis, the study compares mean grain size predictions made with SEDFLUX2D against actual grain sizes measured from core data collected during EuroSTRATAFORM field studies offshore of the Po and Pescara Rivers.

2) The reflectivity experiments for the different sediment mixtures have been completed and thin sections from the experiments have been analyzed for grain size using the autocorrelation algorithm. Results are now being written up.

3) A three-dimensional PDF of reflection loss as a function of grazing angle (0-90°) and frequency (0-3000 Hz) has been developed for the mid-Malta Plateau (mean water depth ~100 m) (Figure 1).

RESULTS

1) The numerical modeling predicts that a mixture of floods and storms produce reflectivities that change from 11 dB for sands on the innermost shelf to 9 dB for muds farther offshore, values that agree with reflectivity measurements for these sediment types (e.g., Hamilton, 1970). On local scales of 100 m or more, however, maximum changes in reflectivity are < 0.5 dB. So are most annual changes in reflectivity over all modeled water depths (0-35 m).

2) The experiments clearly show that as the distribution of grain sizes in deposits increases, seismic reflections from the interface between them become stronger, changing from being almost undetectable when the deposits consist of the same grain size to being detectable when the deposits have even a small range in grain size. The autocorrelation analysis indicates the reflections are associated with a contrast between finer (slower settling) grains in the lower deposit and coarser (more rapidly settling) grains in the overlying deposit. Since the grains are all quartz and so have the same compressional speed, the reflections are presumably being caused by a change in porosity and thus bulk density at the interfaces.

3) On average, reflection loss on the mid-Malta Plateau as measured from ambient ocean noise is a maximum of ~10 dB at ~1500 Hz and a 90° grazing angle. The loss tapers towards 0 dB below ~100 Hz and above ~2000 Hz at a 90° grazing angle, and towards 0 dB for all frequencies down to a grazing angle of ~30° below which there are no returns (Figure 1).

IMPACT/APPLICATIONS

1) For most sonar systems, changes in seabed reflectivity must exceed 2-3 dB in order to be detectable. The modeling result that floods and storms commonly produce annual reflectivity changes of ≤ 0.5 dB suggests that individual such events are not likely to be discernable in repeat sonar surveys.

2) Seismic reflection horizons are commonly interpreted to be time lines, i.e. horizons that are synchronous in time and that follow depositional surfaces. The experiments support this notion with first-time physical evidence that fining caused by sediment settling leads to a contrast in grain size between deposits that in turn leads to the seismic reflections.

3) PDFs of reflection loss derived from ambient ocean noise offer a direct probability estimate of the impact of the seabed on sound propagation in the ocean. This is in contrast to forward modeling efforts that attempt to predict the acoustic impact of the seabed on sound loss through modeling of seabed acoustic behavior from often highly-limited sediment property data.

RELATED PROJECTS

I along with others in a subgroup of the Seabed Team in the Uncertainty DRI (Drs. Kraft (UNH), Overeem (INSTAAR), Holland (PSU), Syvitski (INSTAAR), Mayer (UNH) and Goff (UTIG)) have tested the capability of SEDFLUX2D to predict grain size and compressional sound speed in the GEOCLUTTER study area on the New Jersey continental shelf. In the test, SEDFLUX was used to

model seabed evolution on the shelf from ~40Ky ago up to the present. The final model outputs of grain size, porosity and bulk density were then used in the Buckingham (1997, 1998, 2000) and EDFM (Williams, 2001) acoustic models to compute compressional sound speeds. Finally, these predicted sounds speeds and grain sizes were compared against measured in-situ sounds speeds and grain size analyses from cores. The results are summarized in Kraft et al. (in press).

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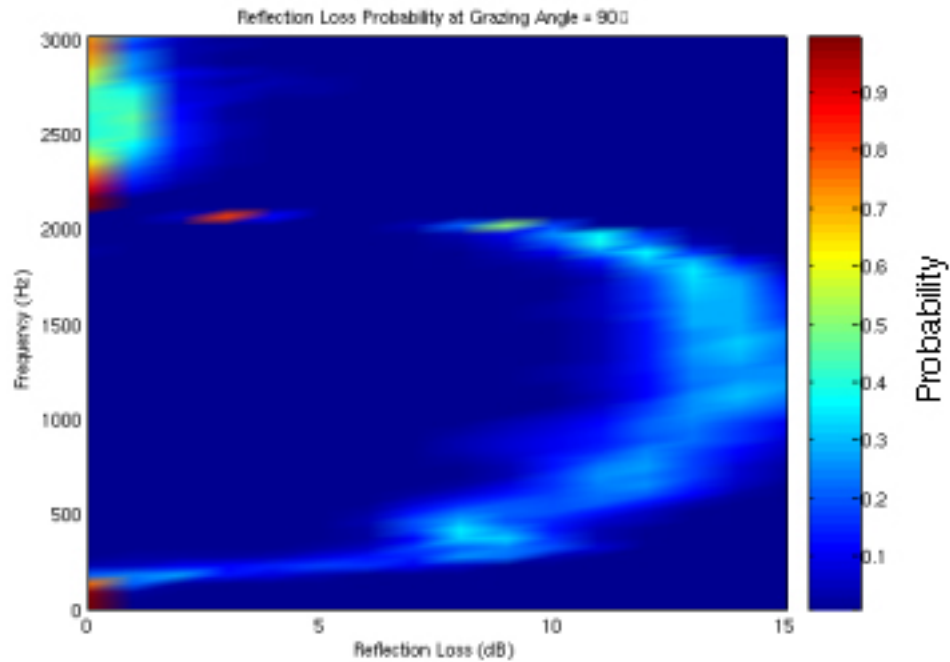


Figure 1. Slice through 3D PDF of reflection loss at the seabed at a grazing angle of 90° (vertical incidence) based on measurements of ambient ocean noise along an ~20 km track across the mid-Malta Plateau averaging ~100 m water depth.